Overview of Scintillation Systems

ANT'11

Daniel Bick

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

October 11, 2011

Outline

1. Motivation
2. Scintillator Requirements for LENA
3. Different Scintillators for Neutrino Detection
4. Scintillator Properties
5. Conclusions

Motivation

- Past and present experiments have shown that liquid scintillator detectors are an excellent choice for detecting neutrinos
- KamLAND and Borexino recently explored neutrino fluxes below 5 MeV in the reactor, solar and geoneutrino sector
- Future experiments will require larger target masses and thus larger volumes
- Highly transparent scintillators needed

Liquid scintillator is well suited for the detection of low energy neutrinos

Requirements for a Next Generation LSD

What should the next liquid scintillator detector offer?

- Good energy resolution
  - More than 200 p.e. per MeV → sufficient light yield needed
- High transparency
  - Large volume requires long attenuation lengths $\mathcal{O}(10\text{-}20\,\text{m})$
- Low detection threshold

  $\bar{\nu}_e$: 1.8 MeV (threshold for inverse β-decay)

  ν_x: $\approx 200\,\text{keV}$ (Intrinsic ^{14}C) → Radiopurity
- Excellent background discrimination
  - Coincidence signal from inverse β-decay
  - Pulse shape discrimination (scintillator type dependent)

Liquid Scintillator

An organic liquid scintillator in general consists of a solvent and one or more solutes.

Solvent

- Hydrocarbon molecules containing benzene-ring structures
- Luminescent → when excited, deexcitation produces UV light
- Spectrum of a single component scintillator has a significant overlap with its own absorption spectrum

Solute(s)

- One or two solutes added as wavelength-shifter or *fluor*
- Energy is transferred e.g. via dipole-dipole interactions or collisions
- Shifts emission spectrum to longer wavelengths where the scintillator is more transparent
- Optimization of emission spectrum to PMT sensitivity

Characteristics of Liquid Scintillators

Emission spectrum

- UV or violet light, light transmission wavelength dependent

Light Yield

- Affects energy resolution and detection threshold

Fluorescence time profile

- Particle-type dependent → particle ID

Attenuation length

- Absorption affects energy resolution
- Scattering affects signal shape

Purity

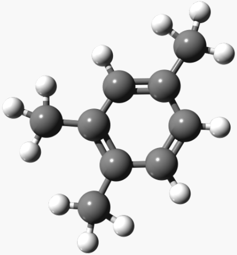
- Radioactive contaminations mimic neutrino signals

Safety

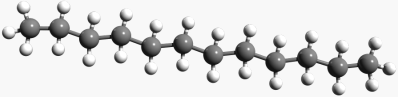
- Environmental and health hazards
- Often low flash points

Solvents: PC

PC C_9H_{12}



Dodecane $C_{12}H_{26}$



PC

- Successfully used in KamLAND and Borexino
- KamLAND: mixture of 80% dodecane, 20% PC
- Attenuation length 8 m @ 430 nm
- Low flash point (48°C)
- Needs to be purified

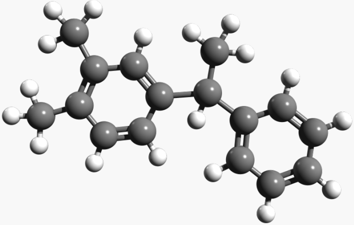
+Dodecane

- High transparency can compensate lower light yield
- Offers many free protons

Solvents: PXE and LAB

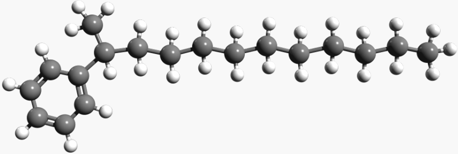
- Attenuation length 12 m (after purification
- High flash point (167°C)
- Fast ($\tau_1 = 2.63$ ns)
- High density (0.986 kg/l)

PXE $C_{16}H_{18}$



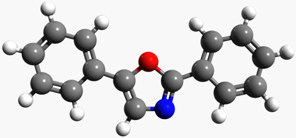
- Attenuation length ~ 20 m
- High flash point (140°C)
- Many free protons (6.6×10^{28} per m^3)

LAB $C_{16-19}H_{26-32}$



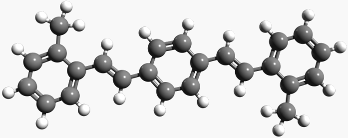
Solutes

PPO $C_{15}H_{11}NO$



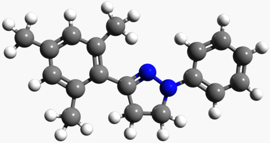
- primary fluor
- absorption: 280-325 nm
- emission 350-400 nm

bisMSB $C_{24}H_{22}$



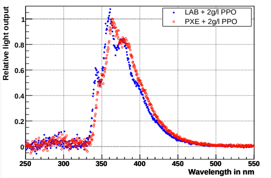
- secondary fluor
- absorption: 320-370 nm
- emission: 384-450 nm

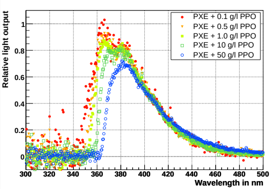
PMP $C_{18}H_{20}N_2$

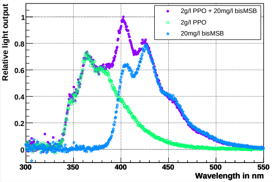


- large stoke shift
- absorption maximum: 294 nm
- emission maximum 415 nm

Emission Spectra







T. Marrodán Undagoitia, PhD thesis 2008

Emission spectra depend on

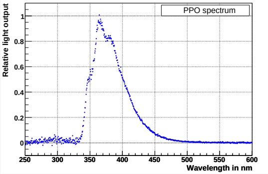
- Solvent
- Type of fluor
- Amount of fluor

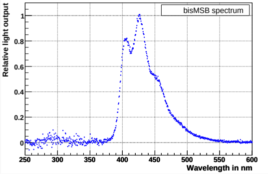
Solvent

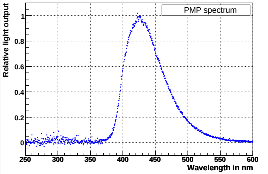
- Typically around 290 nm

Fluor

- Desired to emit above 400 nm







T. Marrodán Undagoitia, arXiv:0904.4602

Light Yield

The amount of light emitted depends not only on the particle's energy:

- Type of scintillator
- Type of particle (quenching)
  - Ionization and radiationless deexcitation processes lead to a loss of fluorescence efficiency
  - Effect higher for heavier particles (protons, α)
  - Affects also pulse shape

Typically $\mathcal{O}(10000)$ photons per MeV

Energy resolution is correlated to the number of detected p.e. per MeV

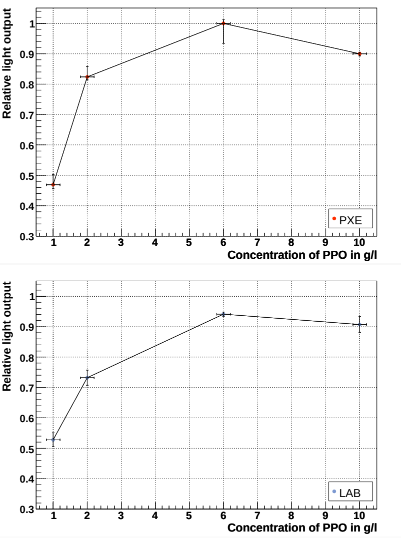
Number of photo electrons

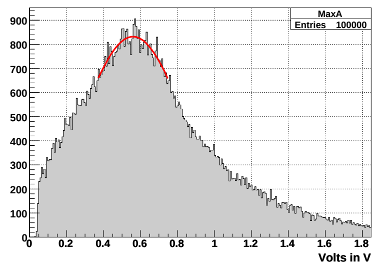
- Primary light output
- Absorption losses
- PMT coverage
- PMT quantum efficiency

Light Output Measurements for LENA

Relative light output compared to PXE + 6 g/l PPO (maximum)

- Scintillator excited by ^{54}Mn source (γ 834 keV)
- Maximum of pulse height spectrum used for comparison
- Light output increases up to 6 g/l PPO





T. Marrodán Undagoitia, PhD Thesis 2008

Florescence Times

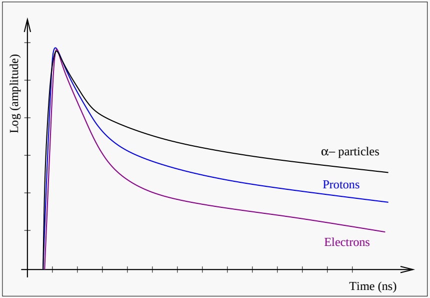
Contributions from decay of different exited states and other processes

Number of excited states

$$n(t) = \sum_i n_i e^{-\frac{t}{\tau_i}}$$

Decay constants τ_i typical for each scintillator

- First (fast) component usually large amplitude ⇒ time response
- Quenching: amplitudes n_i of time components depend on $\frac{dE}{dx}$



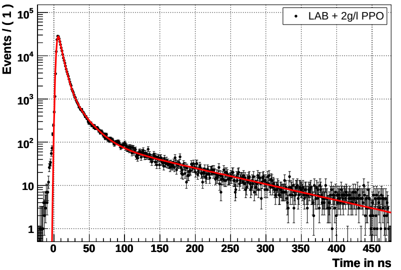
T. Marrodán Undagoitia, PhD Thesis 2008

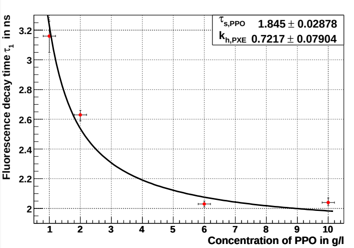
⇒ particle identification by pulse shape analysis

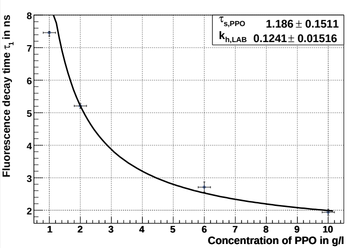
Scintillation pulse shape depends on fluorescence decay times

Measurement of Fluorescence Times for LENA

Measurements performed using *single photon sampling technique*





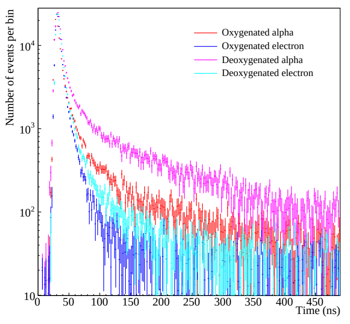


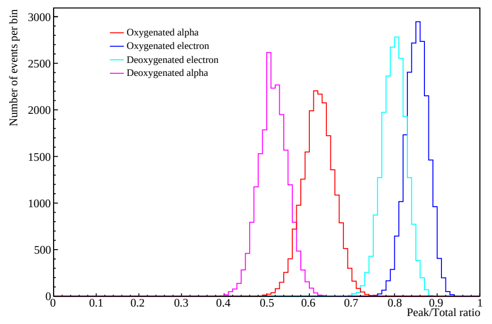
T. Marrodán Undagoitia, arXiv:0904.4602

- Fluorescence decay times decrease with fluor concentration
- Contribution of fast component between 75 and 95%
- Variations of τ_1 between 2 and 8 ns
- PXE significantly faster

α/β dicrimination in LAB

- LAB + 2 g/l PPO (SNO+ Measurements)
- Deoxygenating the scintillator reduces quenching
- Increase of relative amount of longer time components
- Better particle discrimination

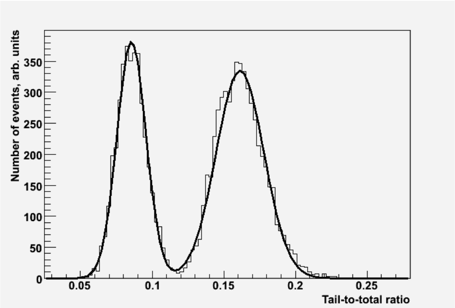




H. M. O'Keeffee, arXiv:1102.0797

Neutron Gamma Discrimination

- Discriminate recoil protons from gammas through pulse shape analysis
- Am-Be source as neutron + γ source



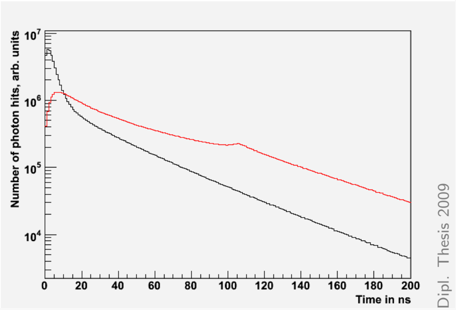
Neutron rejection efficiency
97.8% γ acceptance

Visible Energy [MeV]	Neutron rejection efficiency in PXE [%]	in LAB [%]
0.5-1.1	99.80	93.28
1.1-1.7	99.97	98.27
1.7-2.3	99.99	99.05
2.3-2.9	99.99	99.33
2.9-3.5	99.98	99.36

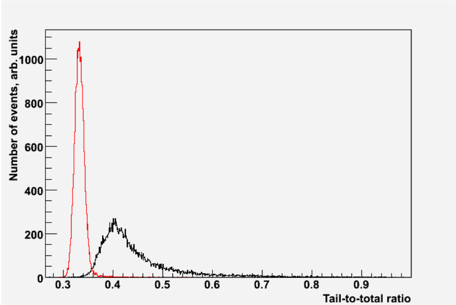
R. Möllenberg, Dipl. Thesis 2009

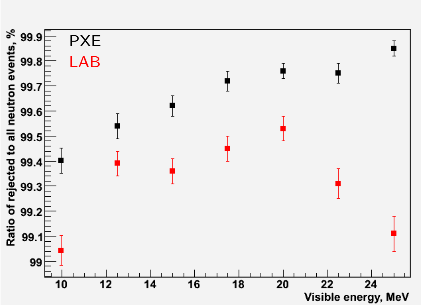
MC of Neutron Gamma Discrimination in LENA

- MC: Works also on large scales
- T.O.F. corrections necessary
- Neutron and positron events generated



R. Möllenberg, Dipl. Thesis 2009





Light Attenuation: Absorption and Scattering

Optical transparency is one of the key parameters for large volumes

Absorption

- prevents some photons from reaching the PMTs

Scattering

- redirects the propagation direction of photons

→ lengthens trajectory

→ smears arrival time and hit patterns

Different contributions to scattering

- Rayleigh scattering on electrons → natural limit $\sim 40\,\mathrm{m}$
- *Absorption and reemission*
- Mie scattering by impurities

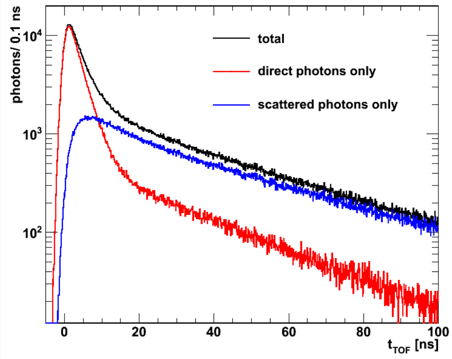
⇒ influences energy, time and spatial resolution

Wavelength-dependent: Transparency increases with the wavelength.

Low absorption and scattering lengths are required

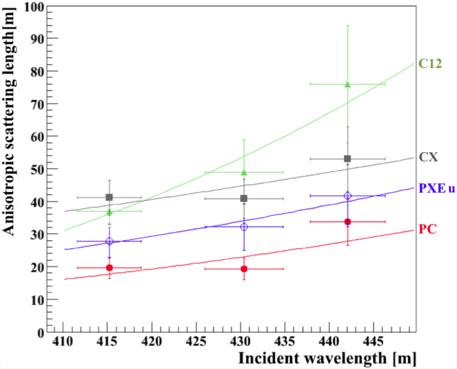
Understanding 3D Light Transport

MC of point like *e* event in LENA



D. Hellgartner, Diploma Thesis, 2011

Anisotropic (Rayleigh) scattering



M. Wurm, arXiv:1004.0811

Sample	ℓ_{is} [m]	ℓ_{an} [m]	ℓ_S [m]	χ^2/ndf	ℓ_{ray}
PXE U	22.8±1.0	33.6±4.0	13.6±0.7±1.0	1.39	32
PXE P	40.0±3.9	51±13	22.3±2.7±1.6	3.71	32
C12 SA	258±54	40.9±3.9	35.3±3.0±2.2	0.92	
C12 AC	132±16	48.5±5.6	35.4±3.1±2.3	0.77	
LAB P500	75.3±5.3	40.2±4.4	26.2±1.9±1.6	1.23	45
LAB P550	60.5±3.7	40.5±5.2	24.3±1.9±1.5	1.29	45
LAB 550Q	66.3±5.7	40.0±4.6	25.0±1.9±1.6	0.80	45
PC	13.0±0.9	19.3±3.3	7.8±0.6±0.6	1.52	21
CX	$>10^3$	45.0±4.5	44.9±4.5±2.9	0.74	44

Purity Issues

Impurity threats

- Dust particles containing K, U, Th
- ^{222}Rn emanating form materials of construction
- ^{85}Kr and ^{39}Ar from air leaks
- ^{210}Pb and ^{210}Po on metal surfaces

Impurities are a source for both background and attenuation

^{14}C is intrinsic to the scintillator and cannot be removed (long storage, old carbon)

Distillation

- Removes impurities that are less volatile
- Does not remove noble gas impurities

Gas Stripping

- Nitrogen flushing
- Removes remaining noble gases very efficiently

Water extraction

- *Washing* the scintillator thus removing polar impurities

Conclusions

State of the art liquid scintillators

- Large attenuation lengths up to $\mathcal{O}(20\,\mathrm{m})$
- Combination of PPO and bisMSB provides high stokes shift and good light yield for both PXE and LAB
- PXE: faster than other scintillators
- LAB: better effective light yield (due to high attenuation length)

- PMP makes second fluor needless but has a reduced light yield
- LAB + PPO + bisMSB currently favored for LENA

End

Single Photon Smapling Technique